EXPERIMENT TO DETERMINE RELATIVE VALUES OF GRAPHIC FORMULAS AS CONTRASTED WITH EMPIRICAL FORMULAS IN TEACHING OF ELEMENTARY CHEMISTRY

IN PARTIAL SATISFACTION
FOR THE REQUIREMENTS FOR THE
MASTER'S DEGREE IN EDUCATION

PRACTICUM IN SECONDARY EDUCATION
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TABLE OF CONTENTS

STATEMENT OF THE PROBLEM

To determine the relative influence of graphic and emperical formulas on chemistry grades.

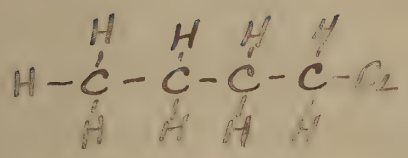
FORMULATION OF THE PROBLEM

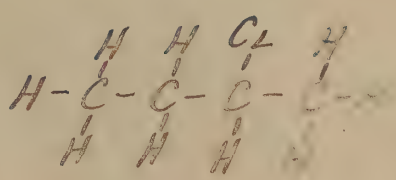
In the teaching of Elementary Chemistry, students have a considerable amount of difficulty in remembering formulas. The student cannot write equations unless he can remember formulas. Therefore, it is important that some method to make memorization of formulas easier be found. Much of the work in Elementary Chemistry has to do with the solving of problems, and in order that these problems may be solved, the equations must be memorized. As has been said, before the student can correctly write an equation, he must accurately remember all of the formulas involved.

Therefore, remembering formulas is very essential.

H_2O is the formula for water. This means that a molecule of water, the smallest piece of water that can exist and still be water, consists of two atoms of Hydrogen and one atom of Oxygen chemically combined. This is very simple. This is what we call an empirical formula. It expresses the fact that two atoms of Hydrogen are united with one atom of Oxygen, but more information than this is often required.

An empirical formula does not show how the elements are united. That is, it doesn't show whether the Hydrogens are linked together and the Oxygen added onto the end of the chain, or whether one Hydrogen is united to one side of the Oxygen atom and the other Hydrogen atom, to the other side. Sometimes it is necessary to know this. In organic chemistry, where we have to do with very complex compounds, the formulas of each are often very long and empirical formulas are sometimes of very little use. Therefore, another method of writing formulas, known as the Graphic Method, has been devised. By means of graphic formulas, the structure of a compound is shown. For instance, the two formulas below are Graphic formulas:





The empirical formula C_4H_9Cl expresses either of them but does not differentiate between the two, and yet there is a difference between the two. In one case, the Chlorine is united to a Carbon atom which is in turn, united to another Carbon atom and two Hydrogen atoms. This is known as Primary Monochlorethane. In the other compound, the Chlorine atom is united to a Carbon atom, which is in turn united to two other Carbon atoms and one Hydrogen atom. This is Secondary Monochlorentane.

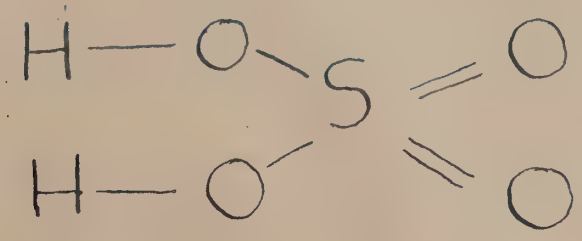
These two compounds are not alike. The difference in the position of the chlorine atom make a difference in the properties of the compounds. They are entirely separate and distinct compounds with separate properties.

The empirical formula does not show this: being the same for both compounds. And so, graphic formulas have grown up in the science of Chemistry, and are of a great deal of use and importance to the chemist.

It occurred to me to wonder whether graphic formulas, by presenting a picture to the eye of the student, might not be more easily remembered than empirical formulas.

The lines in the above graphic formulas, which connect one atom with another, represent the valence of the various elements. Thus, there are four lines radiating from each Carbon atom. This indicates that the Valence of Carbon is four. Radiating from each Hydrogen atom there is one line because the Valence of Hydrogen is one. The Valence of Chlorine is one and accordingly, there is one line radiating from each Chlorine atom.

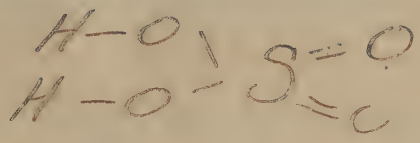
A knowledge of Valence is very necessary in the study of Chemistry. Now if I write the empirical formula H_2SO_4 there is nothing in it to indicate the vlaences of the various elements. If, on the other hand, I write the formula graphically as follows:



and the student knows that the number of lines radiating from each atom is the same as its valence, it follows that if he knows the graphic formula, he also knows the valence. If, on the other hand, the student knows the valences of various elements, it should be an aid to him in writing the graphic formula. Thus, in the very simple case of water, the Hydrogen has a valence of one and the Oxygen has a valence of two.

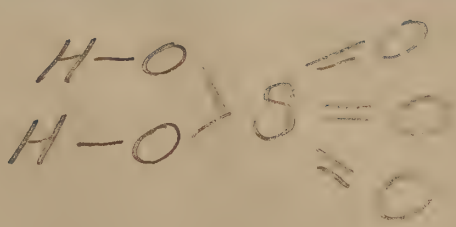
Obviously, the formula for water must be H_2O as indicated by the following graphic formula:

Consider the following formula for sulphuric acid.



From this formula it is clear that the valence of Sulphur is six, valence of Oxygen, two, and the valence of Hydrogen, one. The empirical formula is H_2SO_4. Suppose the student forgets whether the formula is H_2SO_3, H_2SO_4 or H_2SO_5. If he writes a graphic formula, know the valences of the three elements involved, he will discover at once that the formula must be H_2SO_4. In H_2SO_3 the valence of the Sulphur would have to be four, as shown in the following graphic sketch:

Since the student knows the valence of Sulphur is six, it follows that the formula of Sulphuric acid cannot be H_2SO_5. In H_2SO_5 the valence of the Sulpnur would have to be eight, as shown in the following graphic formula:



Since the valence of Sulphur is not eight, obviously H_2SO_4 is not the formula of Sulphuric acid.

From these considerations it occurred to me that a knowledge of graphic formulas might be of some value to the student as and aid to memorizing formulas and indirectly, since formulas are used in writing equations, and in solving problems, be an aid in the learning of Chemistry generally.

PROCEDURE

Two groups of Seniors in the South Philadelphia High School for Boys were used in this experiment. Their ages ranged from 16 to nearly 19 years. There were 24 boys in each group.

When the boys entered school in September, they were given achievement tests in chemistry two or three times a week for about six weeks. During this period the instruction in chemistry in both groups was as nearly the same as possible. At the end of six weeks, a more elaborate test than any so far given was administered. This was not a standardized test.

The purpose of all this testing was to determine how nearly alike the two groups were in their ability to master chemistry when taught in exactly the same way. The results of these final tests are given on page [illegible]. During the next seven weeks, one group was taught the graphic method of writing formulas and the other group was taught the empirical method of writing formulas. An attempt was made to keep the instruction exactly the same for both groups in all other particulars.

The ages of the student were taken from statements of the students themselves. The students were asked whether they worked after school or not and this data is included in the table of page [illegible]. It was believed that the size of the students' roster would have an influence on his ability to learn chemistry and therefor the roster load for each student is also given on page [illegible].

During the second seven weeks, the boys were tested by home-made chemistry test two or three times a week and at the end of the period, were given an elaborate test covering the work of the entire period. This data is given on page [illegible].

After the experiment was completed, an intelligence test, the Terman Group Test, was administered to both groups for the purpose of determing how

nearly the two groups were alike in ability. The results of this test are given in the table on page 13 .

So far as could be determined, none of the boys had had any previous experience in chemistry. None of them were repeaters.

The two groups are referred to in this report as B-4 and B-5.

THE PRESENTATION OF THE DATA

THE first task was to determine whether the two groups were alike. First of all with regard to age.

Their ages are as follows:

B-4		B-5	
Yr.	Mon.	Yr.	Mon.
18	9	18	6
18	8	18	4
17	10	17	11
17	9	17	10
17	9	17	9
17	8	17	9
17	5	17	7
17	5	17	6
17	4	17	6
17	4	17	6
17	2	17	4
17	2	17	3
17	0	17	3
16	11	17	3
16	11	17	2
16	7	17	2
16	7	17	1
16	7	17	0
16	1	17	0
16	1	16	5
		16	5
		16	2

AUSTIN LOAD

(45 Minute Periods)

B-4	B-5
36	39
36	39
36	36
34	36
34	35
34	35
33	35
33	34
32	32
32	32
32	32
30	32
30	31
30	31
29	31
26	31
26	31
26	31
26	30
26	27
26	27
26	27
26	26
25	23

TOTAL GRADE EARNED BY END OF FIRST SEMESTER

B-4	B-5
92	88
92	87
86	87
85	86
85	82
84	81
82	81
81	79
80	78
80	75
79	71
76	68
76	68
75	68
74	65
72	64
72	63
60	62
60	57
59	51
59	48
51	42
44	35
34	32

TOTAL GAMES PLAYED DURING SECOND HALF WEEKS

B-4	B-5
96	84
93	80
92	75
91	75
85	72
84	68
81	62
81	61
80	59
80	56
80	57
78	57
76	56
72	55
70	52
70	52
66	48
65	45
64	44
60	43
54	43
42	42
40	41
23	31

COEFFICIENTS OF CORRELATION

	Between I. Q. and Grade Earned at End of First Seven Weeks.	Between I. Q. and Grade Earned During Second Seven Weeks.	Between Grade Earned During First Seven Weeks And Grade Earned During Second Seven Weeks.
B-4	.223	.162	.856
B-5	.421	.300	.516

INTELLIGENT MORONS

No. of Student		I. Q.		Grade Earned At End of first 7 weeks.		Grade Earned During Second 7 weeks.	
B-4	B-5	B-4	B-5	B-4	B-5	B-4	B-5
22	4	1.196	1.030	82	65	80	52
6	12	1.134	1.025	92	87	91	75
18	18	1.057	1.025	44	78	42	62
3	16	1.052	1.019	72	86	81	75
8	7	1.051	1.009	76	81	76	56
12	10	1.034	.994	60	82	65	80
16	6	1.028	.977	84	63	92	43
14	17	1.019	.966	80	87	80	84
2	1	.999	.947	85	79	81	55
23	19	.995	.941	80	62	78	44
11	8	.992	.919	86	42	70	31
9	11	.972	.911	59	68	70	72
10	24	.971	.885	66	68	40	57
21	23	.965	.882	92	81	96	57
13	5	.931	.875	74	51	60	49
7	9	.912	.870	72	75	72	58
15	13	.906	.870	75	64	66	43
19	21	.890	.812	81	68	84	45
17	20	.879	.809	76	71	85	61
4	15	.875	.718	34	35	23	42
5	2	.867		51	48	64	52
24	3	.846		59	32	54	48
20	14	.817		85	88	93	68
1	22	.805		79	57	80	41
Average		966	924	73	67	72	56

SUMMARY OF COMPILED INFORMATION

No. of Boy according to roll.		Grade Earned at end of 1st 7 weeks.		Grade Earned at end of 2 7 weeks.		* Indicates boy works after school		Age in Yrs. and Months.		45 Min. Periods On Roster.	
B-4	B-5	B-4	B-5	B-4	B-5	B-4	B-5	B-4	B-5	B-4	B-5
1	1	79	79	80	55			17-5	17-6	26	32
2	2	85	48	81	52			17-8		30	
3	3	72	32	81	48		*	16-7	17-10	26	35
4	4	34	65	23	52	*		18-8	17-6	33	32
5	5	51	51	64	49	*	*	17-5	18-6	32	35
6	6	92	63	91	43	*	*	16-1	17-6	25	36
7	7	72	81	72	56	*	*		17-3	30	32
8	8	76	42	76	31		*	17-9	17-9	26	32
9	9	59	75	70	58	*	*	16-1	17-1	33	36
10	10	66	82	40	80	*	*		16-0	25	27
11	11	86	68	70	72		*	16-7	17-3	30	31
12	12	60	87	65	75			16-11	16-5	32	23
13	13	74	64	60	43	*	*	17-0	17-2	34	32
14	14	80	88	80	68		*	17-2	17-9	36	30
15	15	75	35	66	42	*	*	17-10	18-4	34	35
16	16	84	86	92	75	*	*	17-9	17-3	36	27
17	17	76	87	85	84	*	*	17-2	17-0	36	26
18	18	44	78	42	62	*			16-2	39	39
19	19	81	62	84	44	*	*	16-7	17-2	26	39
20	20	85	71	93	61	*	*	17-4	16-5	26	30
21	21	92	68	96	45	*	*	16-11	17-11	26	34
22	22	82	57	80	41		*		17-0	29	31
23	23	80	81	78	57		*	17-4	17-7	26	27
24	24	59	68	54	57	*		18-9	17-4	32	31

CRITICAL ANALYSIS OF DATA

The average I.Q. for B-4 was .966. The average I.Q. for B-5 was .924. These I.Q.'s are just about normal, being very nearly one and are pretty closely alike. This establishes the fact in so far as the method is reliable, that the two groups were of about equal intelligence. It may be worth pointing out that there was a slight difference between the two groups and the group of the higher I.Q. made the better achievement scores.

The coefficient of correlation between the I.Q.'s and the grade at the end of the first seven weeks was .265 for B-4. This is ~~also~~ positive correlation but is very low and seems to indicate almost no correlation at all. This is surprising since success in chemistry should depend more upon native ability than success in some other subjects and might very well furnish material for a future investigation.

A still greater discrepancy is indicated in the fact that the coefficient of correlation between the I.Q. and the grades earned during the second seven weeks for B-4 is still lower, being .162 and this is almost zero correlation and would ~~leave~~ cause one to suppose that intelligence is not a factor in acquiring chemical information. In other words, it seems that we are probably stressing memory more than reason.

There is a very high degree of correlation between the grade earned at the end of the first seven weeks and the grade earned at the end of the second seven weeks in B-4. The coefficient of correlation is .856.

The figures for B-5 can be obtained from page 18. They show a higher degree of correlation between the I.Q. and the grades earned and a lower degree of correlation between the grades themselves. This is strange and unusual and it is difficult to see why the figures in B-4 are not very nearly the same as those in B-5, since the two groups were of about the same native

ability to start with.

The average of the marks in B-4 at the end of the first seven weeks was 73. The average of the marks in B-4 earned during the next seven weeks was 72. This is pretty close agreement and it is just about what one would expect, since these boys were not taught graphic formulas but were taught the old method of writing formulas. Not only were the averages closely alike but the distribution was pretty much the same in both groups, as indicated by the coefficient of correlation of .856.

In B-5 the average of the grades earned at the end of the first seven weeks was 67. This is five points lower than the average in B-4 for the same period. The I. Q.'s in B-5 were also a trifle lower than the I. Q.'s in B-4 it will be remembered. So that this somewhat lower average score is not so surprising as it would have been if the discrepancy in the I. Q.'s had been the other way around. But the average grade in B-5 for the second seven weeks was only 56. This indicates a falling off of nearly 17% in average grade. So far the data seems to indicate the following:

Two groups of boys of nearly equal I. Q.'s with about equal ability in chemistry were taught during the second seven weeks of the term by different methods. The group taught by one method (empirical formulas) did about the same grade of work during the second seven weeks as they did during the first seven weeks, while the marks of the group taught by the second method (graphic formulas) fell off 17%.

The ages of the boys were useful in determining their I. Q.'s and also serve to show that the two groups were of about the same average age and that the age distribution was about the same in both groups. There was, however, quite a difference between the ages of the youngest and the oldest in each group. This difference amounting to 2 years and 4 months in B-5 and 2 years and 8 months in B-4.

Regarding after school work not much can be said. The boys' own statements were taken as to whether they worked after school or not and no standard was set as to what should be regarded as after school work. Some boys may run a few errands which would take only an hour or so and other may serve paper route for an hour or two in the evening and then usher in the theatre for the rest of the night. Obviously, the latter employment would interfere considerably with the boys work while the former might not. Therefore, not much dependence was placed upon the factor of after school work. However, 18 boys in B-5 Work or claim to work after school, while only 15 in B-4 work or claim to Work. One would expect the marks to be lower in the class where more of the boys work and this is consistent with the data. Expressed in another way, 75% of the boys in B-5 work; 64% of the boys in B-4 work, so that there is 11% more employment in B-5 than in B-4.

The average mark at the end of the first seven weeks in B-5 was 6 points lower than the average mark in B-4. Perhaps because of the greater employment in B-5.

The lowest grade at the end of the first seven weeks in B-4 was 34. This boy was 18 years and 8 months of age, works after school, carries a heavy roster of 35 periods. After the experiment, his grade was 23. Evidently consistently poor, due perhaps, to the heavy roster and the after school work. He was the next to the oldest boy in the Section. Higher age seems to indicate retardation.

The lowest grade earned in B-5, at the end of the first seven weeks, was 32. This boy has 35 periods on his roster, is 17 years and 10 months of age, works after school. He came into the class late. At the end of the experiment his grade was 48. The fact that he came in late is probably more significant than any of the other factors ~~or all of the other factors~~. If the results of the experiment show anything in this case, it seems to be that teaching of graphic formulas was a help to this boy, but as a matter of fact, I do not think the results show anything.

At the end of the first seven weeks in B-5 there were boys who earned 55, 42, 51, and 57. At the end of the experiment these boys had the following grades:

Grade at End of first 7 weeks.	Age Yrs.-Mos.	Grade at End of Experiment.
57	17-0	41
55	18-4	42
42	17-9	31
51	18-6	59

All of these boys worked after school. They all carried rosters of 31 or more periods per week. In every case the grade at the end of the experiment was either lower than it was at the beginning or had not improved by much. In two cases it had improved but very little. Here again it seem evident that other factors are much more significant than the teaching of graphic formulas. These boys were poor students to start and were poor student at the end .

graphic formulas were unable to make good students of them and when one considers the very heavy rosters and the fact that they worked after school the result is not surprising.

In 3-4, at the end of the first seven weeks, that is, before there was any differentiation between the work of the two classes, there were eight boys ~~in 3-4~~ with grades between 80 and 90. The grades and the other information concerning these students are given in the following table:

Grade at End of first 7 weeks.	Grade at End of Experiment.	Periods on Roster.	Age Yr.-Mon.	Employment After School.
85	81	30	17 8	No
86	70	30	16 7	No
80	80	36	17 2	No
84	92	36	17 9	Yes
81	84	26	16 7	Yes
85	93	26	17 4	Yes
82	80	29	** *	No
80	78	26	17 4	No

In the above table it seems, on the whole, as though the grade on the second report was pretty much the same as the grade on the first report in five out of the eight cases. In the other three cases, the grade increased in two of them and decreased in one. The boy whose grade decreased had a roster of 30 periods, he did not work after school but was comparatively young, being one of the two youngest in the group. I do not know ~~whether~~ WHY his grade went down. There does not seem to be any justification for it in any of the data which I have. In the other two cases, that is, where the grade went up, one boy has a heavy roster of 36 periods and the other boy has a light roster of 26 periods; both boys work after school and one is nearly a year older than the other. ~~Whether~~ WHY the grade

went up in either case I do not know but it is probably the result of added work or greater ~~modification~~ MOTIVATION for one reason or another and seems not to be connected very definitely with age, roster, or outside work. Now, on the whole, it seems that the good students in B-4 that is, those whose grades fell between 80 and 90 at the end of the first seven weeks, continued to be good students during the next seven weeks or improved to such an extend that they became excellent students, this latter being true only in two cases; or became fair students, this being true only in one case; but in the vast majority of the cases, as was to be expected, the grade did not change by much.

Now let us consider the boys in B-5 whose grades at the end of the first seven weeks fell between 80 and 90. There were seven cases. The grades were as follows:

GRADES
81
82
87
88
86
87
81

Pretty nearly the same number of boys as in group B-4. This is normal and natural and just what one would expect.

The total score of those whose grades were between 80 and 90 in B-5 was 592. The total score of seven of those whose grades were between 80 and 90 in B-4 was 583 so that, if anything, the boys in B-5 did slightly better than those in B-4. It will be remembered that B-5 was the Section that was taught the graphic method of writing formulas and B-4 was the Section taught the empiric method or writing

formulas.

Now compare the grades at the end of the experiment with those at the end of the first seven weeks for Section B-5.

Grade at End of first 7 Weeks.	Grade at End of Experiment	Periods on Roster.	Age Yr.-Mon.	Employment after School
81	56	31	17 3	Yes
82	80	27	16 0	Yes
87	75	23	16 5	No
88	68	30	17 9	Yes
86	75	27	17 3	Yes
87	84	26	17 0	Yes
81	57	27	17 7	Yes

From the above table it is evident that in every case the mark at the end of the experiment was lower than the mark at the beginning. Age distribution in B-5 is just about the same in both groups. Six of the boys in B-5 worked after school as contrasted with three in the same group in B-4 so that, as far as after school work is concerned, there would seem to be some RELATIONSHIP between it and the decrease in grade, though I can hardly believe that this one factor alone would account for the difference. It would certainly tend to do so.

Let us consider the roster load. So far as this factor is concerned, the advantage was all with B-5 since only two of them had rosters with 30 or more periods on them and these were 30 and 31 respectively, whereas in B-4 4 of the rosters had 30 periods or more on them and two of these were 36 periods. So that, as far as roster load is concerned, B-5 should have done better than B-4. Actually they did worse.

It seems then that something caused the boys in B-5 to fall down during the

second third of the term. This may have been due to outside work and it may have been due to the fact that in B-5 graphic formulas were taught while in B-4 they were not.

As in so many experiments of this kind it is impossible to get two groups exactly alike. These groups were not exactly alike. They differ apparently in after school work and who can say how important this difference was. That one difference may have upset the whole experiment. It was in this group, that is the good students--those between 80 and 90, that I expected to find the grades improved due to the introduction of the graphic formulas. The BEST group, that is, those whose grades ranged from 90 to 100, are so good that there is not much room for improvement and those whose grades are poor, that is, below 60, are probably not capable of much improvement, but the average group, with grades ranging from 70 to 90, are capable of improvement. They probably have intelligence enough to profit by an improved method and there is room in their marks for improvement.

Let us consider, therefore, the grade range from 70 to 80, as we have seen the evidence in the grade range from 80 to 90, for any improvement in grade due to the introduction of graphic formulas, is all negative. Let us see whether it is the same with the grade range from 70 to 80.

Statistics covering these cases are given for B-4 in the following table:

Grade for First Seven Weeks.	Grade At End of Experiment	Periods on Roster	Age Yr.-Mon.		Employment After School
79	80	26	17	5	No
72	81	26	16	7	No
72	72	30	**	*	Yes
76	76	26	16	1	No
74	60	34	17	0	Yes

Grade at End of First 7 Weeks.	Grade at End of Experiment	Periods on Roster	Age Yr.-Mon.	Employment After School
75	66	34	17 10	Yes
76	85	36	17 2	Yes

From these figures it seems that in five cases out of seven the grade remained the same or improved; two cases out of the seven it fell down. These two boys have fairly heavy rosters and they work after school, both good reasons why the grade might be expected to fall down. However, there was one boy with a heavier roster than either of these two, who worked after school and his grade went up so that he finally had the highest grade in this group.

Now let us compare this B-4 group with the corresponding group in B-5. That is, the boys in B-5 whose grades, at the end of the first seven weeks before there was any differentiation in the course, were between 70 and 80.

The data covering these boys are given in the following table:

Grade for First Seven Weeks.	Grade at End of Experiment	Periods on Roster	Age Yr.-Mon.	Employment After School
79	55	32	17 6	No
75	58	36	17 1	Yes
78	62	39	16 2	No
71	61	31	16 5	Yes
68	72	31	17 3	Yes
68	45	34	17 11	Yes
68	57	31	17 4	No

Unfortunately there were not the same number of boys in this grade group in B-5 as there were in B-4 and in order to get an even number for purposes of matching I have added to this group the three boys whose grades came nearest to this group. They each had a grade of 68. Since this is the case, that is, since

I had to add three boys from the next lower group of course the grades in this group, at the end of the first seven weeks, are on the whole lower than those of the corresponding group of B-4. However, in every case but one the grade at the end of the experiment was lower than the grade at the beginning of the experiment. The rosters for this group were, on the whole, heavier than the rosters for the corresponding group in B-4 and this might account for the difference. I don't believe it does but it might. So far as age distribution and out of school work are concerned the two groups are about alike.

Now remembering that the group which fell down as a result of the teaching is the group that was taught the graphic method of writing formulas. It seems possible and even likely that the decrease in efficiency is the result of this method. There are so many other factors that might have modified these grades, factors that one might not think of, factors that one may think of but cannot control, there are so many of these factors that although the low grades might be the result of the graphic method, I feel pretty sure that they are not. I think there was something else that accounted for it, and I shall discuss this later under a discussion of the results.

Conclusion

The only conclusion that could be drawn from the data, if any can be drawn, is that graphic formulas not only are not a help in learning chemistry but are rather a hinderance. This conclusion, however, may not be valid because there may be many factors influencing the data which have not been taken into account. In the first place, the groups were so small that anything that influenced the marks of two or three boys would change the results by 8 or 10%.

A factor which may be of some importance is the fact that B-4 met in the seventh period and the B-5 class met in the eighth period of the day; the eighth period being the last period of the day, which might easily be that the boys in B-5 would be influenced by this fact, they might be more tired for instance, and the grades in B-5 might therefor suffer.

Another factor which may be even more important is the frame of mind of the teacher. After having taught the subject to one class, the teacher may be a little tired of the subject and may be inclined to skip through it rather hastily with the next class. This, of course, is a grevious fault on the part of the teacher and should be carefully guarded against. No doubt it is guarded against but it may still occur to some extent.

To sum the whole thing up in a word, the data is probably insufficient to draw a valid conclusion but so far as it goes, it indicates that graphic formulas should not be taught in the high school.

BIBLIOGRAPHY

"The Reader's Guide" and the "Journal of Chemical Education," as well as a number of other educational and chemical magazines, have been consulted, but no reference to any experiment on this subject has been discovered. Therefore, a bibliography is impossible.